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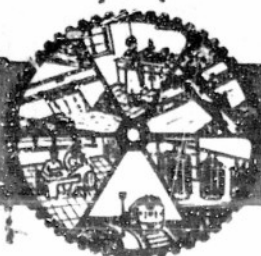
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**THE UNIVERSITY OF TENNESSEE
DEPARTMENT OF ELECTRICAL ENGINEERING**

**DEVELOPMENT
OF A
HIGH FREQUENCY
STEERABLE ANTENNA**

Classification cancelled in accordance with
Executive Order 10461 issued 5 November 1953

Theresa B. Weaver 7/23/54 Document Service Center
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Navy Department
Bureau of Ships
Electronics Divisions

Interim Development
Report No. 9

Contract No. NObnr-57448
Index No. NE-091035 ST7
10 June 1953

**A PROJECT OF THE ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE COLLEGE OF ENGINEERING**

Knoxville 10, Tennessee

Inc 11

Emel (45) to the project 327 5-11

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INTERIM DEVELOPMENT REPORT
FOR
DEVELOPMENT OF A HIGH FREQUENCY
STEERABLE ANTENNA

This report covers the period
1 May 1953 to 31 May 1953

ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE
KNOXVILLE, TENNESSEE

Navy Department

Electronics Divisions

Bureau of Ships

Contract No. NObsr-57448

Index No. NE-091035 ST7

10 June 1953

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ABSTRACT

This report covers work done on Contract No. NObsr-57448 Index No. NE-091035 ST7, at The University of Tennessee during the month of May 1953.

The following was accomplished:

1. The design of the system for obtaining antenna patterns by means of an automatic recorder was completed.
2. The work on the propagation analysis was continued.
3. More significant data on angles-of-arrival have been received.
4. Two methods of steering horizontally the beam of a rhombic antenna have been considered. One method is not successful, but the other method has some promise of being useful.
5. The mathematical analysis of the propagation characteristics of a circular travelling-wave antenna was completed and the results are being checked.
6. The study of circular arrays having horizontal patterns which are invariant with frequency was continued.

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PART I

Purpose

This project involves the development of a high frequency steerable antenna having the following characteristics:

1. It shall be operable throughout the frequency range of 4 to 32 megacycles per second.
2. It shall be capable of four, or more, simultaneous transmissions on different frequencies, and at different azimuth and elevation angles.
3. For each transmission, it shall be capable of being directed to any azimuth angle and to any elevation angle between the horizon and 30° above the horizon.

The communication system shall provide reliable 24-hour day-to-day communication with a 20-decibel signal-to-noise ratio. The ranges to be covered are from approximately 500 nautical miles to 4000 nautical miles.

The development consists of two phases:

Phase I. Theoretical and experimental studies.

Phase II. Development of design criteria.

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General Factual Data

Personnel:

F. V. Schultz	Project Director	85 1/2	Man-hours
W. D. Leffell*	Assistant Engineer	25	Man-hours
W. J. Bergman	Junior Engineer	56	Man-hours
L. W. Ricketts*	Junior Engineer	43 1/2	Man-hours
H. P. Neff	Junior Engineer	168	Man-hours
G. R. Turner	Secy-Draftsman	84	Man-hours
L. Phillips*	Technician	76	Man-hours
D. Marcum	Student Computer	32	Man-hours
H. Knox	Student Computer	120	Man-hours
D. J. Smith	Typist	4 3/4	Man-hours

* Preparation of antenna test facility.

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- Harrison, C. W., "The Radiation Field of Long Wires, with Application to Vee Antennas," Journal of Applied Physics, Vol. 14, p. 537, October 1943.
- "Ionospheric Radio Propagation," U.S. Department of Commerce, National Bureau of Standards Circular No. 462, June 1948, Washington, D.C.
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- Lewin, L., "Rhombic Transmitting Aerial," Wireless Engineer, May, 1941.
- McLachlan, N. W., Bessel Functions for Engineers, Oxford University Press, New York, 1943, Chapter 3.
- Watson, G. N., Treatise on the Theory of Bessel Functions, McMillan Co., 1944, p. 368.

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Williams, H. P., Antenna Theory and Design, Pitman and Sons, Ltd., London, 1950.

Harrison, C. W., Jr., "The Inclined Rhombic Antenna," Proceedings of the Institute of Radio Engineers, Vol. 30, p. 241, May 1942.

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Detail Factual Data

1. A system has been designed for controlling the motion of the antenna mount, and its synchronization with the recorder, from within the building at the antenna test facility. The selsyn system for driving the recorder in synchronism with the antenna mount was designed. Construction of the selsyn system was started.
2. By using the two daily operating frequencies determined last month for each path, for January 1953, the median expected field intensities have been calculated. These values are listed in Tables 1 to 3, together with the values previously obtained by using the optimum working frequency in each case. The two daily operating frequencies have been determined for each path for June 1947 and these values will be used for calculating median expected field intensities.
3. More significant data on angles-of-arrival have been received. There is a possibility of receiving information from one more source so no analysis of the data on hand has been attempted. The antenna development has not progressed far enough to require a careful analysis of this information immediately.
4. The investigation of the possibility of steering horizontally the beam of a rhombic antenna by varying the phase of the current in the two legs on one side of the antenna with respect to the current in the other two legs, has been completed. The results are shown in Figures 1, 2 and 3. Figure 1 shows the free-space horizontal pattern of a rhombic antenna of optimum design with no phase shift introduced. Figure 2 is for the same antenna but with the current in the left half lagging that in the right half by a phase angle of 45 degrees. This phase angle is 90 degrees for the antenna the pattern of which is given by Figure 3. The method obviously is not a successful one. This had been predicted on the basis of physical considerations but it was considered necessary to actually make calculations to substantiate the physical reasoning.
5. A method of steering horizontally the beam of a rhombic antenna by using two opposite legs of a different length from the other two legs is being investigated. The results so far obtained are shown in Figures 4, 5 and 6. The method seems to hold considerable promise, although the practical problems may turn out to be difficult.
6. Time was not available during the month for further investigation of the possibilities of using inclined radial wires as tilted V-antennas.

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Detail Factual Data - Continued

7. The mathematical analysis of the radiation characteristics of a circular travelling-wave antenna was completed. This analysis is now being checked.
8. The work reported last month on a circular array for which the horizontal pattern is invariant with frequency was continued. By the use of several rings, patterns of considerable sharpness can be obtained. Exact spacings of these concentric rings are not critical. To obtain beamwidths of the narrowness required for the present task, an excessively large number of rings is required, so the method seems to have little immediate utility.

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DEPARTMENT OF ELECTRICAL ENGINEERING
ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE

PROJECT PERFORMANCE AND SCHEDULE

Index No. NE-091035 ST7

Contract No. NObsr-57448

Date: 10 June 1953

Legend: Work Performed

Period Covered: 1/5/53 to 31/5/53

Schedule of Projected Operation

Subject	1952					1953											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N		
1. Development of Field Test Facilities.																	
2. Study of Propagation Problem.																	
a. Investigation of paths lying entirely in night region.																	
b. Investigation of paths lying entirely in day region.																	
c. Investigation of paths lying partly in day and partly in night region.																	
d. Investigation of auroral refraction.																	
3. Determination of Suitable Antenna Type of Types.																	
a. Search of literature.																	
b. Theoretical Study.																	
4. Detailed Theoretical and Experimental Investigation of Most Promising Antenna Types.																	
5. Development of Network System Suitable for Driving Array.																	
6. Experimental Study of Final Array.																	
7. Preparation of Phase Report.																	

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Conclusions

1. The work on the propagation problem has not progressed far enough to allow the drawing of any conclusions.
2. The attempt to steer horizontally the beam of a rhombic antenna by varying the phase of the current in the two legs on one side of the antenna with respect to the current in the other two legs, was unsuccessful.
3. The possibilities of steering horizontally the beam of a rhombic antenna by using two opposite legs of a different length from the other two legs, appear to be promising.
4. Work on the circular travelling-wave antenna has not progressed sufficiently to permit the drawing of any conclusions.
5. The use of circular arrays having patterns that do not change with frequency still appears to be unfeasible. Highly directive horizontal patterns can now be obtained, but only at the expense of a large number of concentric rings of elements.

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Program for Next Interval

1. The construction of the recording system for the antenna test facility will be continued, and possibly completed.
2. Median expected field intensities for June 1947 will be calculated, using the two daily operating frequencies already determined.
3. The practicality of steering horizontally the beam of a rhombic antenna by using two opposite legs of a different length from the other two legs will be considered.
4. It is believed that some time will be available for further consideration of the possibilities of using inclined radial wires as tilted V-antennas.
5. The actual field patterns produced by a circular travelling-wave antenna will be computed.

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NO. 359-11. 10 x 10 to the half inch, 5th lines accented.
Engraving, 7 x 10 in.
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Figure 1

Free-space Horizontal Pattern of Rhombic Antenna
with Current in One Side at an Angle of 6 with
Respect to That of the Other Side.

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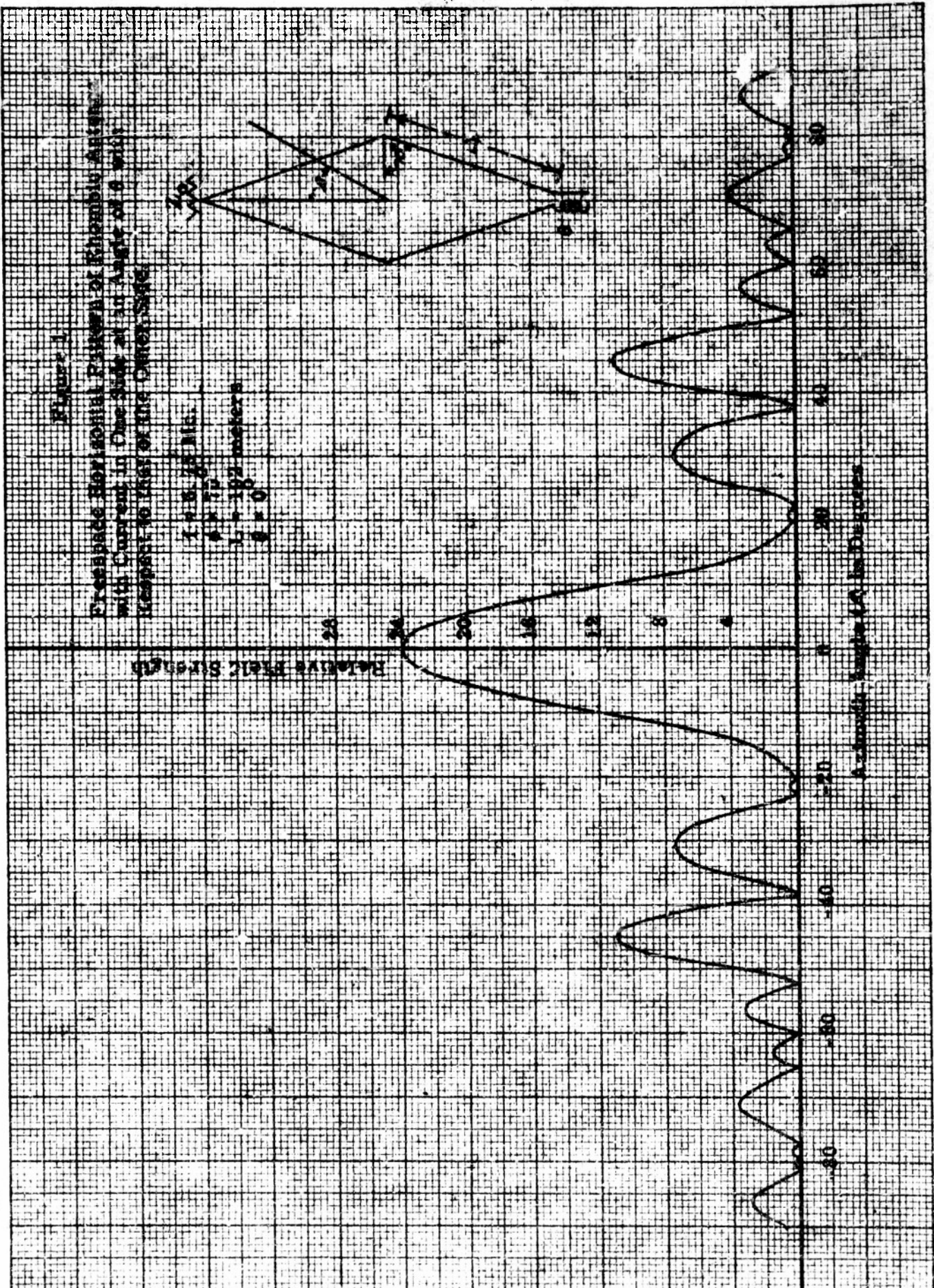
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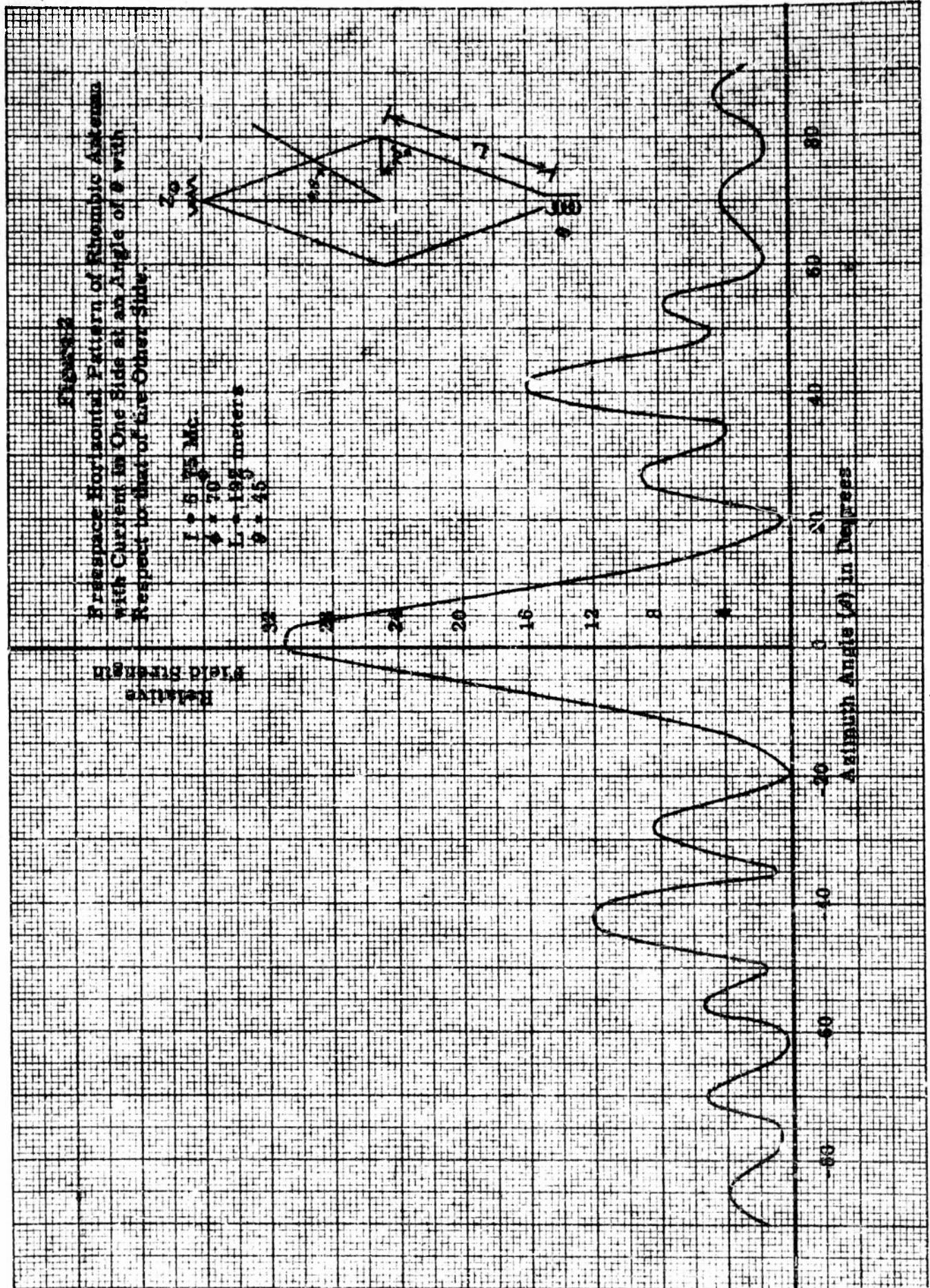
Relative Field Strength

Antenna Length 100 Meters



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Figure 3

Free-space Horizontal Pattern of Resonant Antenna
with Current in One Side at an Angle of θ with
Respect to that of the Other Side.

$f = 8.75$ Mc.

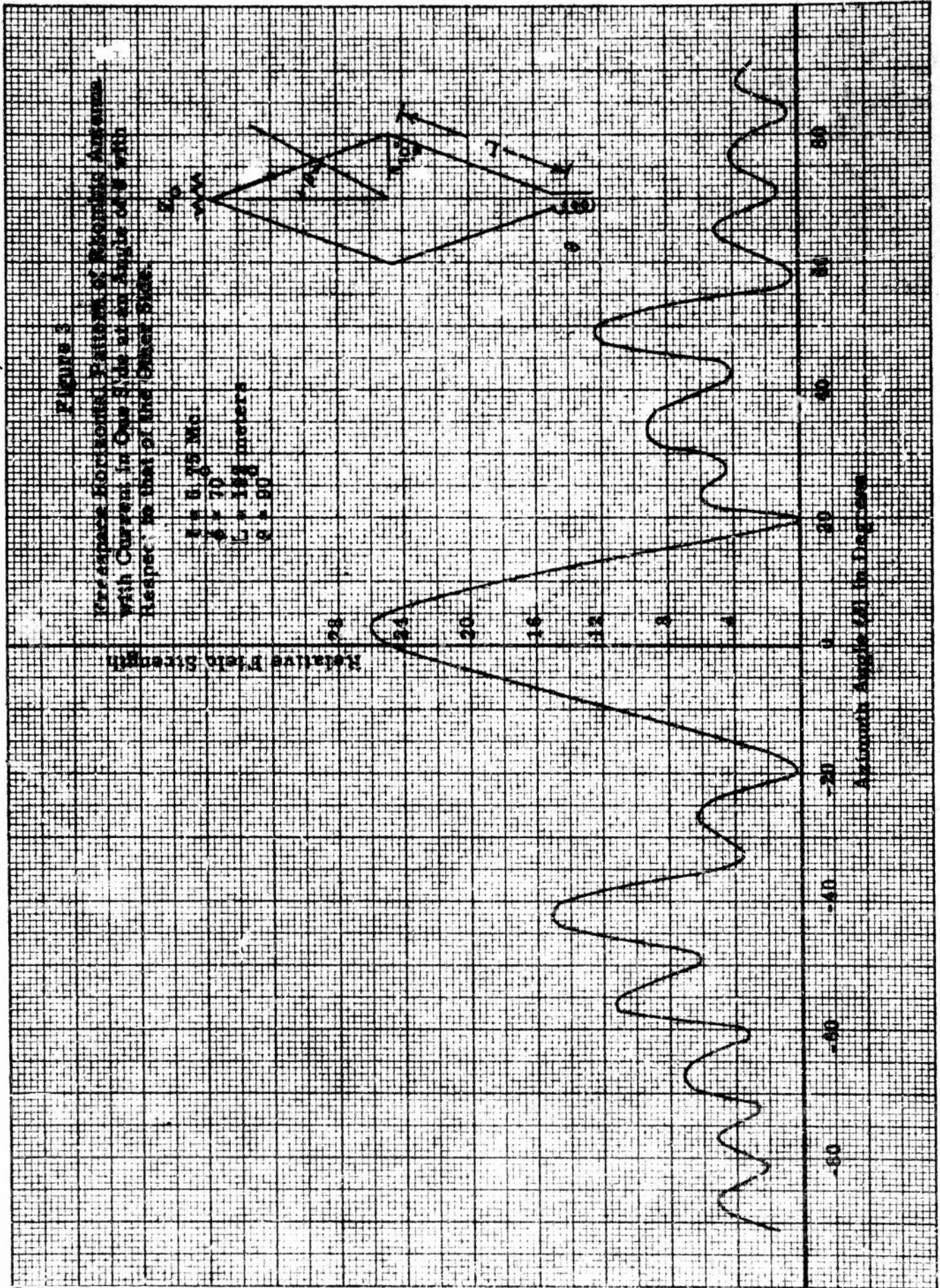
$h = 70$

$L = 188$ meters

$R = 90$

Relative Field Strength

Antenna Angle θ in Degrees



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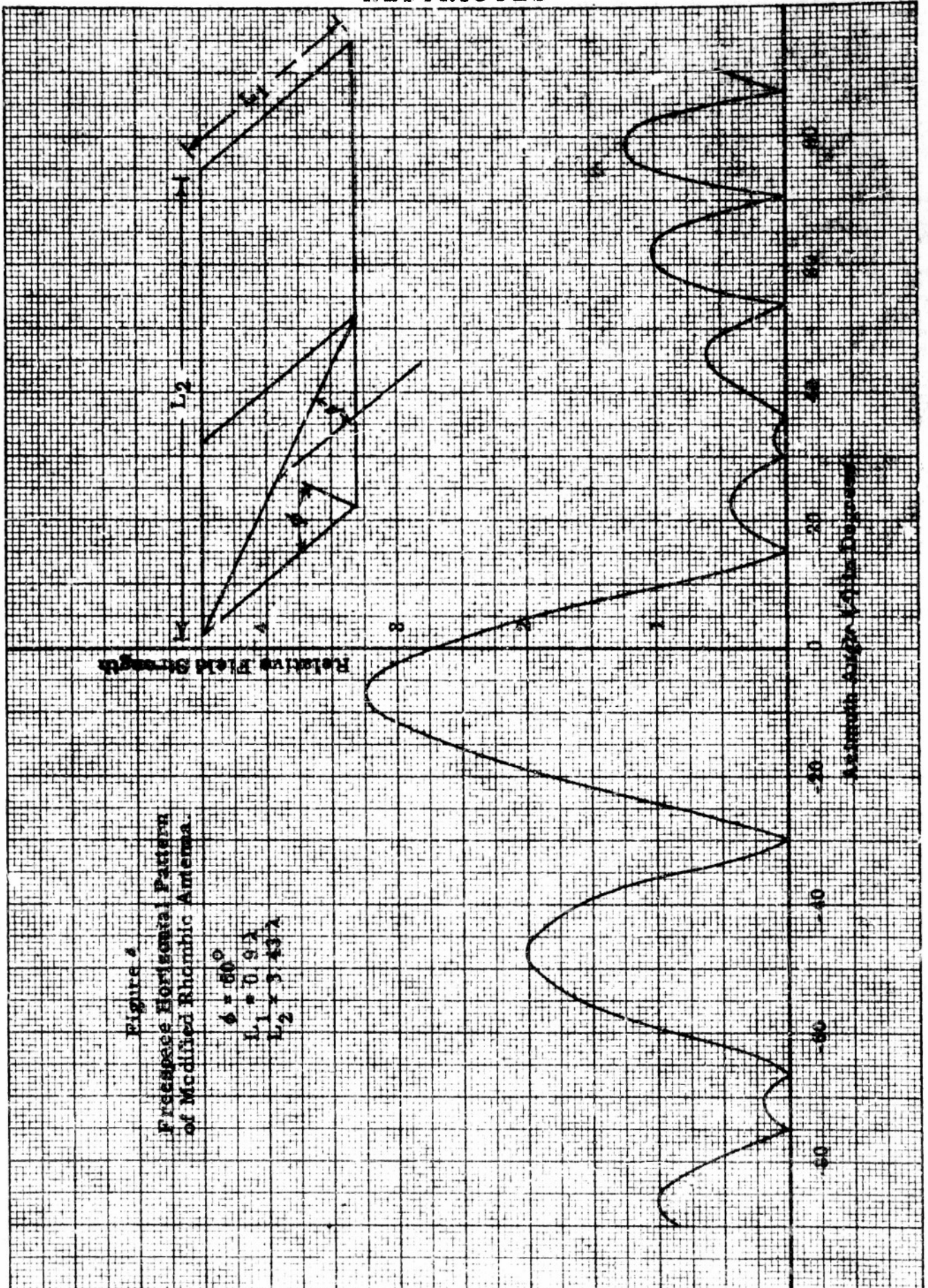
NO. 359-1. 10 x 10 to the half inch, 5th times accentuated.
Engraving, 7 x 10 in.
MADE IN U. S. A.

Figure 2
Prescribed Horizontal Pattern
of Modified Rhombic Antenna

$$\begin{aligned} \phi &= 60^\circ \\ L_1 &= 0.9\lambda \\ L_2 &= 3.43\lambda \end{aligned}$$

Relative Field Strength

Azimuth Angle in Degrees



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Figure 5

Freespace Horizontal Pattern
of Modified Rhombic Antenna.

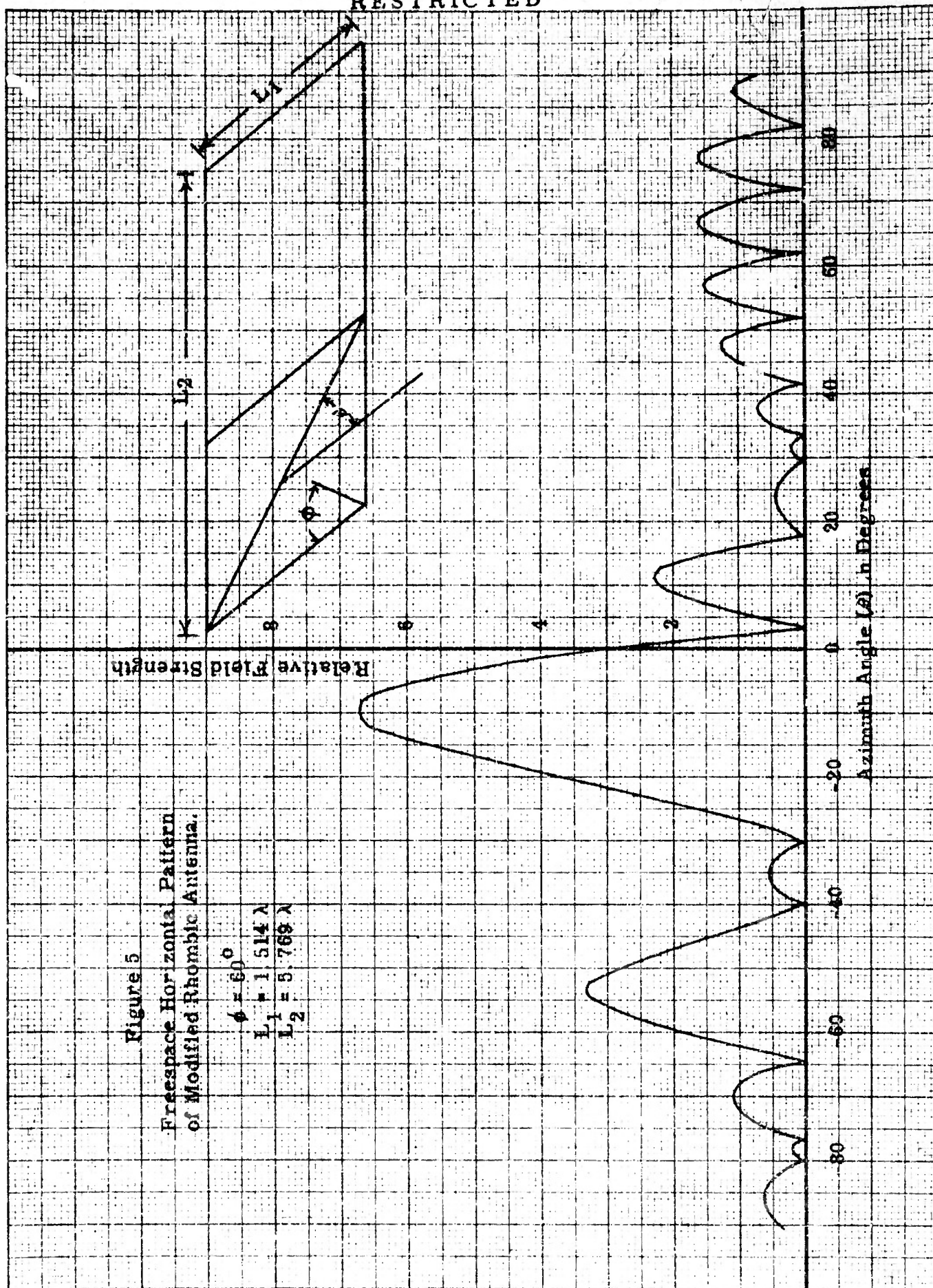
$$\phi = 60^\circ$$

$$L_1 = 1.514 \lambda$$

$$L_2 = 5.769 \lambda$$

Relative Field Strength

Azimuth Angle (θ) in Degrees

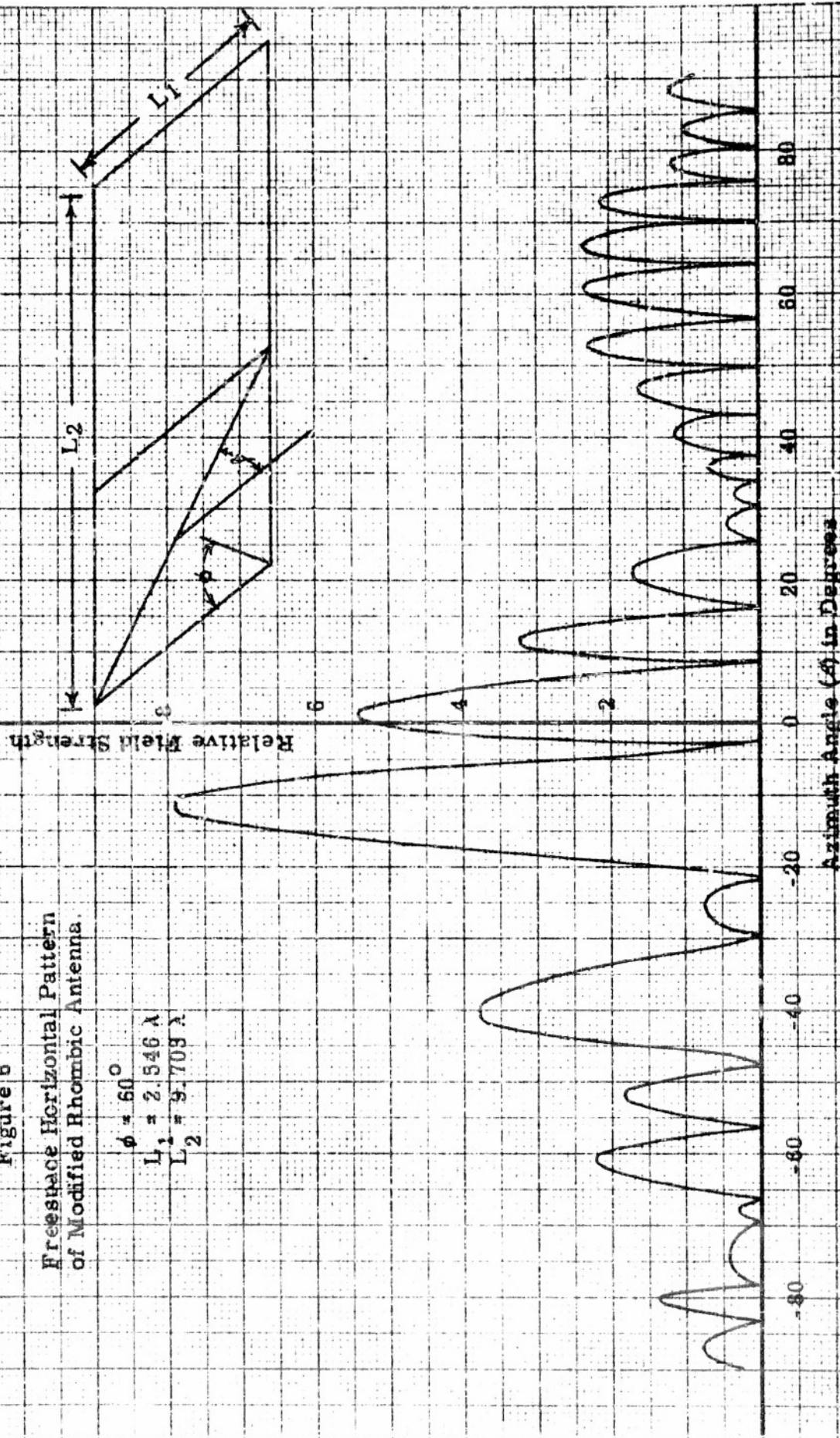


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Figure 6

Free-space Horizontal Pattern
of Modified Rhombic Antenna.

$\phi = 60^\circ$
 $L_1 = 2.546 \lambda$
 $L_2 = 3.709 \lambda$



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TABLE I

Field Strengths Calculated for a Transmitter Located at Port Lyautey, French Morocco

Calculations made for: January 1953; sunspot number = R = 30; 1 kilowatt radiated power; 0000 hours and 1200 hours.

North from Port Lyautey

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v/m}$)	Operating Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v/m}$)
Km.	Nautical Miles					
800	432	1-Hop-F2	3.5	44.5	3.2	44.5
1200	648	1-Hop-F2	4.3	42.0	4.0	42.0
3200	1728	1-Hop-F2	7.6	34.5	5.8	34.5

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v/m}$)	Operating Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v/m}$)
Km.	Nautical Miles					
800	432	1-Hop-F2	8.5	36.0	5.8	22.0
1200	648	1-Hop-F2	10.6	35.0	7.2	19.0
3200	1728	1-Hop-F2	19.6	31.0	13.6	18.5

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TABLE I
(continued)South from Port Lyautey

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v}/\text{m}$	Operating Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v}/\text{m}$
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	2.8	44.5
1200	648	1-Hop-F2	4.2	42.0	3.0	42.0
3200	1728	1-Hop-F2	7.6	34.5	4.4	34.5
8000	4320		11.8	23.0	5.0	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v}/\text{m}$	Operating Frequency (Mc.)	Median Field Intensity (db above $1 \mu\text{v}/\text{m}$
Km.	Nautical Miles					
800	432	1-Hop-F2	9.6	36.0	6.6	24.5
1200	648	1-Hop-F2	12.7	34.5	8.4	23.0
3200	1728	1-Hop-F2	28.8	30.0	20.4	23.5
8000	4320		23.7	11.0	17.0	-1.0

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TABLE I
(continued)

East from Port Lyautey

0600 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	3.4	44.5
1200	648	1-Hop-F2	4.3	42.0	4.0	42.0
3200	1728	1-Hop-F2	7.8	34.5	7.6	34.5
8000	4320		8.1	23.0	7.2	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	8.7	35.0	6.4	29.0
1200	648	1-Hop-F2	11.0	33.5	7.6	27.0
3200	1728	1-Hop-F2	20.4	28.0	15.6	24.0
8000	4320		15.6	13.0	12.8	8.0

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TABLE I
(continued)

West from Port Lyautey

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	3.2	44.5
1200	648	1-Hop-F2	4.2	42.0	3.9	42.0
3200	1728	1-Hop-F2	5.6	34.5	5.2	34.5
8000	4320		5.9	23.0	5.2	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	8.9	36.0	6.0	28.0
1200	648	1-Hop-F2	11.1	34.0	7.0	24.0
3200	1728	1-Hop-F2	18.6	28.0	15.0	24.5
8000	4320		8.9	22.0	13.6	13.0*

* Taken at 1300 hours.

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TABLE 2

Field Strengths Calculated for a Transmitter Located at Seattle, Washington

Calculations made for: January 1953; sunspot number = R = 30; 1 kilowatt effective radiated power; 0000 hours and 1200 hours.

North from Seattle

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v}/\text{m}$	Operating Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v}/\text{m}$
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	2.2	44.5
1200	648	1-Hop-F2	3.8	42.0	2.8	42.0
3200	1728	1-Hop-F2	5.0	34.5	4.8	34.5

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v}/\text{m}$	Operating Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v}/\text{m}$
Km.	Nautical Miles					
800	432	1-Hop-F2	7.6	37.5	5.2	31.0
1200	648	1-Hop-F2	9.6	36.5	6.8	31.5
3200	1728	1-Hop-F2	17.4	30.5	12.8	29.0

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TABLE 2
(continued)

South from Seattle

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	3.3	44.5
1200	648	1-Hop-F2	4.3	42.0	4.0	42.0
3200	1728	1-Hop-F2	7.9	34.5	6.6	34.5
8000	4320		8.9	23.0	6.6	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	8.0	36.5	6.4	31.0
1200	648	1-Hop-F2	10.4	34.5	7.2	31.5
3200	1728	1-Hop-F2	20.8	32.0	17.0	29.0
8000	4320		20.4	9.0	17.0	2.0

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TABLE 2
(continued)

East from Seattle

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	2.8	44.5	2.4	44.5
1200	648	1-Hop-F2	3.4	42.0	3.1	42.0
3200	1728	1-Hop-F2	7.1	34.5	6.4	34.5
8000	4320		5.1	23.0	4.8	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	7.2	35.5	5.2	30.0
1200	648	1-Hop-F2	9.1	35.0	6.8	30.0
3200	1728	1-Hop-F2	15.8	29.5	11.9	27.0
8000	4320		6.8	15.0	6.8	15.0

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TABLE 2
(continued)

West from Seattle

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v/m}$	Operating Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v/m}$
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	2.8	44.5
1200	648	1-Hop-F2	4.0	42.0	2.8	42.0
3200	1728	1-Hop-F2	4.8	34.5	4.0	34.5
8000	4320		5.1	23.0	4.6	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v/m}$	Operating Frequency (Mc.)	Median Field Intensity (db above $1\mu\text{v/m}$
Km.	Nautical Miles					
800	432	1-Hop-F2	7.6	37.5	6.0	34.0
1200	648	1-Hop-F2	9.8	36.5	6.8	30.0
3200	1728	1-Hop-F2	17.4	30.0	12.8	27.0
8000	4320		6.8	15.0	8.0	17.0

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TABLE 3

Field Strengths Calculated for a Transmitter Located at Adak, Alaska

Calculations made for: January 1953; sunspot number = R = 30; 1 kilowatt effective radiated power; 0000 hours and 1200 hours.

North from Adak

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	2.8	44.5
1200	648	1-Hop-F2	3.9	42.0	3.4	42.0
3200	1728	1-Hop-F2	6.4	34.5	4.6	34.5

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	7.9	39.0	5.2	33.0
1200	648	1-Hop-F2	10.0	37.0	7.0	33.5
3200	1728	1-Hop-F2	17.0	32.5	10.0	30.0

RESTRICTED

TABLE 3
(continued)

South from Adak

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.5	44.5	3.2	44.5
1200	648	1-Hop-F2	4.3	42.0	3.7	42.0
3200	1728	1-Hop-F2	8.0	34.5	6.8	34.5
8000	4320		8.5	23.0	7.2	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	7.7	36.5	6.0	32.5
1200	648	1-Hop-F2	10.1	36.0	7.6	30.0
3200	1728	1-Hop-F2	22.1	28.5	16.0	24.0
8000	4320		14.4	-6.0	14.4	-6.0

RESTRICTED

TABLE 3
(continued)

East from Adak

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.0	44.5	2.8	44.5
1200	648	1-Hop-F2	3.3	42.0	2.4	42.0
3200	1728	1-Hop-F2	5.2	34.5	4.6	34.5
8000	4320		6.0	23.0	5.2	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	7.5	38.0	5.2	33.0
1200	648	1-Hop-F2	9.3	37.0	5.6	28.5
3200	1728	1-Hop-F2	16.2	32.0	11.0	29.0
8000	4320		7.8	20.0	7.6	19.0

~~RESTRICTED~~

TABLE 3
(continued)

West from Adak

0000 Hours

Distance		Trans Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	3.4	44.5	2.8	44.5
1200	648	1-Hop-F2	3.4	42.0	3.3	42.0
3200	1728	1-Hop-F2	6.0	34.5	4.8	34.5
8000	4320		6.0	23.0	4.8	23.0

1200 Hours

Distance		Trans. Mode	Opt. Working Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m	Operating Frequency (Mc.)	Median Field Intensity (db above 1 μ v/m
Km.	Nautical Miles					
800	432	1-Hop-F2	8.0	39.0	6.0	35.5
1200	648	1-Hop-F2	10.2	38.0	7.2	33.5
3200	1728	1-Hop-F2	16.7	32.5	12.0	30.0
8000	4320		7.7	19.5	6.8	18.5

~~RESTRICTED~~

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